THE

LAURENTIAN ROCKS OF CANADA:

ON THE

OCCURRENCE IN THEM OF ORGANIC REMAINS,

BY

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ON THE

STRUCTURE OF THEIR ORGANIC REMAINS,

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ADDITIONAL NOTE ON THE

STRUCTURE AND AFFINITIES OF EOZOON CANADENSE,

BY

W. B. CARPENTER, M.D., F.R.S., F.G.S.;

AND ON THE

MINERALOGY OF CERTAIN OF THEIR ORGANIC REMAINS,

BY

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1. *On the* Occurrence *of* Organic Remains *in the* Laurentian Rocks *of* Canada. By Sir W. E. Logan, LL.D., F.R.S., F.G.S., Director of the Geological Survey of Canada.

The oldest-known rocks of North America are those which compose the Laurentian Mountains in Canada and the Adirondacks in the State of New York. By the investigations of the Geological Survey of Canada, they have been shown to be a great series of strata, which, though profoundly altered, consist chiefly of quartzose, aluminous, and argillaceous rocks, like the sedimentary deposits of less ancient times. This great mass of crystalline rocks is divided into two groups, and it appears that the Upper rests unconformably upon the Lower Laurentian series.

The united thickness of these two groups in Canada cannot be less than 30,000 feet, and probably much exceeds it. The Laurentian of the West of Scotland also, according to Sir Roderick Murchison, attains a great thickness. In that region the Upper Laurentian, or Labrador series, has not yet been separately recognized; but, from Mr. McCulloch's description, as well as from the specimens collected by him, and now in the Museum of the Geological Society of London, it can scarcely be doubted that the Labrador series occurs in Skye. The labradorite and hypersthene-rocks from that island are identical with those of the Labrador series in Canada and New York, and unlike those of any formation at any other known horizon. This resemblance did not escape the notice of Emmons, who, in his description of the Adirondack Mountains, referred these rocks to the hypersthene-rock of McCulloch, although these observers on the opposite sides of the Atlantic looked upon them as unstratified. In the 'Canadian Naturalist' for 1862, Mr. Thomas McFarlane, for

some time resident in Norway, and now in Canada, drew attention to the striking resemblance between the Norwegian primitive gneiss formation, as described by Naumann and Keilhau, and observed by himself, and the Laurentian, including the Labrador group; and the equally remarkable similarity of the lower part of the primitive slate formation to the Huronian series, which is a third Canadian group. These primitive series attain a great thickness in the north of Europe, and constitute the main features of Scandinavian geology.

In Bavaria and Bohemia there is an ancient gneissic series. After the labours in Scotland, by which he was the first to establish a Laurentian equivalent in the British Isles, Sir Roderick Murchison, turning his attention to this central European mass, placed it on the same horizon. These rocks, underlying Barrande's Primordial zone, with a great development of intervening clay-slate, extend southward in breadth to the banks of the Danube, with a prevailing dip towards the Silurian strata. They had previously been studied by Gümbel and Crejci, who divided them into an older reddish gneiss and a newer grey gneiss. But, on the Danube, the mass which is furthest removed from the Silurian rocks being a grey gneiss, Gümbel and Crejci account for its presence by an inverted fold in the strata, while Sir Roderick places this at the base, and regards the whole as a single series, in the normal fundamental position of the Laurentian of Scotland and of Canada. Considering the colossal thickness given to the series (90,000 feet), it remains to be seen whether it may not include both the Lower and Upper Laurentian, and possibly, in addition, the Huronian.

This third Canadian group (the Huronian) has been shown by my colleague, Mr. Murray, to be about 18,000 feet thick, and to consist chiefly of quartzites, slate-conglomerates, diorites, and limestones. The horizontal strata, which form the base of the Lower Silurian in Western Canada, rest upon the upturned edges of the Huronian series, which, in its turn, unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact.

The united thickness of these three great series may possibly far surpass that of all the succeeding rocks, from the base of the Palæozoic series to the present time. We are thus carried back to a period so far remote, that the appearance of the so-called Primordial fauna may by some be considered a comparatively modern event. We, however, find that, even during the Laurentian period, the same chemical and mechanical processes which have ever since been at work disintegrating and reconstructing the earth's crust were in operation as now. In the conglomerates of the Huronian series there are enclosed boulders derived from the Laurentian, which seem to show that the parent rock was altered to its present crystalline condition before the deposit of the newer formation, while interstratified with the Laurentian limestones there are beds of conglomerate, the pebbles of which are themselves rolled fragments

Fig. 1.—*Section from Petite Nation Seigniory to St. Jerome* (66 miles).

a. Lower Silurian.
b. Upper Laurentian.
b'. Upper Laurentian limestone.
c. Fourth gneiss.
d'. Third limestone.
d. Third gneiss.
e'. Second limestone.
x. Porphyry.
y. Granite.

of still older laminated sand-rock, and the formation of these beds leads us still further into the past.

In both the Upper and Lower Laurentian series there are several zones of limestone, each of sufficient volume to constitute an independent formation. Of these calcareous masses it has been ascertained that three, at least, belong to the Lower Laurentian. But as we do not as yet know with certainty either the base or the summit of this series, these three may be conformably followed by many more. Although the Lower and Upper Laurentian rocks spread over more than 200,000 square miles in Canada, only about 1500 square miles have yet been fully and

Fig. 2.—*Section across Trembling Mountain* (21 miles).

b. Upper Laurentian.	*e'.* Second limestone.
c. Fourth gneiss.	*e.* Second gneiss.
d'. Third limestone.	*f'.* First limestone.
d. Third gneiss.	*f.* First gneiss.

connectedly examined in any one district, and it is still impossible to say whether the numerous exposures of Laurentian limestone met with in other parts of the province are equivalent to any of the three zones, or whether they overlie or underlie them all.

In the examination of these ancient rocks, the question has often naturally occurred to me whether, during these remote periods, organic life had yet appeared on the earth. The apparent absence of fossils from the highly crystalline limestones did not seem to offer a proof in negation, any more than their undiscovered presence in newer crystalline limestones, where we have little doubt they have been obliterated by metamorphic action; while the carbon which, in the form of graphite, constitutes beds, or is disseminated through the calcareous or siliceous strata of

the Laurentian series, seemed to be an evidence of the existence of vegetation, since no one disputes the organic character of this mineral in more recent rocks. My colleague, Dr. T. Sterry Hunt, has argued for the existence of organic matters at the earth's surface during the Laurentian period from the presence of great beds of iron-ore, and from the occurrence of metallic sulphurets; and, finally, the evidence was strengthened by the discovery of supposed organic forms. These were first brought to me, in October 1858, by Mr. J. McCulloch, then attached, as an explorer, to the Geological Survey of the province, from one of the limestones of the Laurentian series, occurring at the Grand Calumet, on the River Ottawa.

Any organic remains which may have been entombed in these limestones would, if they retained their calcareous character, be almost certainly obliterated by crystallization; and it would only be by the replacement of the original carbonate of lime by a different mineral substance, or by an infiltration of such a substance into all the pores and spaces in and about the fossil, that its form would be preserved. The specimens from the Grand Calumet present parallel or apparently concentric layers, resembling those of *Stromatopora*, except that they anastomose at various points. What were at first considered the layers are composed of crystallized pyroxene, while the then supposed interstices consist of carbonate of lime. These specimens, one of which is figured in the 'Geology of Canada,' page 49, called to memory others which had, some years previously, been obtained from Dr. James Wilson, of Perth, and were then regarded merely as minerals. They came, I believe, from masses in Burgess, but whether in place is not quite certain; and they exhibit similar forms to those of the Grand Calumet, composed of layers of dark-green silicate of magnesia (loganite), while what was taken for the interstices are filled with crystallized dolomite. If the specimens from both these places were to be regarded as the result of unaided mineral arrangement, it appeared to me strange that identical forms should be derived from minerals of such different composition. I was therefore disposed to look upon them as fossils, and as such they were exhibited by me at the meeting of the American Association for the Advancement of Science, at Springfield, in August 1859. In 1862 they were shown to some of my geological friends on this side of the Atlantic; but no microscopic structure having been observed belonging to them, few seemed disposed to believe in their organic character, with the exception of my friend Professor Ramsay.

One of the specimens had been sliced and submitted to microscopic examination, but unfortunately it was one of those composed of loganite and dolomite. In these, minute structure rarely occurs. The true character of the specimens thus remained in suspense until last winter, when I accidentally observed indications of similar forms in blocks of Laurentian limestone which had been brought to our museum by Mr. James Lowe, one of our explorers, to be sawn up for marble. In this case the forms were composed of serpentine

and calcspar; and slices of them having been prepared for the microscope, the minute structure was observed in the first one submitted to inspection. At the request of Mr. Billings (the palæontologist of our Survey), the specimens were confided for examination and description to Dr. J. W. Dawson, of Montreal, our most practised observer with the microscope, and the conclusions at which he has arrived are appended to this communication. He finds that the serpentine, which was supposed to replace the organic form, really fills the interspaces of the calcareous fossil. This exhibits in some parts a well-preserved organic structure, which Dr. Dawson describes as that of a Foraminifer, growing in large sessile patches after the manner of *Polytrema* and *Carpenteria*, but of much larger dimensions, and presenting minute points which reveal a structure resembling that of other Foraminiferal forms, as, for example, *Calcarina* and *Nummulina*. Dr. Dawson's description is accompanied by some remarks by Dr. Sterry Hunt on the mineralogical relations of the fossil. He observes that, while the calcareous septa which form the skeleton of the Foraminifer in general remain unchanged, the sarcode has been replaced by certain silicates which have not only filled up the chambers, cells, and septal orifices, but have been injected into the minute tubuli, which are thus perfectly preserved, as may be seen by removing the calcareous matter by an acid. The replacing silicates are white pyroxene, serpentine, loganite, and pyrallolite or rensselaerite. The pyroxene and serpentine are often found in contact, filling contiguous chambers in the fossil, and were evidently formed in consecutive stages of a continuous process. In the Burgess specimens, while the sarcode is replaced by loganite, the calcareous skeleton, as has already been stated, has been replaced by dolomite, and the finer parts of the structure have been almost wholly obliterated. But in the other specimens, where the skeleton still preserves its calcareous character, the resemblance between the mode of preservation of the ancient Laurentian *Foraminifera* and that of the allied forms in Tertiary and Recent deposits (which, as Ehrenberg, Bailey, and Pourtales have shown, are injected with glauconite) is obvious.

The Grenville specimens belong to the highest of the three already mentioned zones of Laurentian limestone, and it has not yet been ascertained whether the fossil extends to the two conformable lower ones, or to the calcareous zones of the overlying unconformable Upper Laurentian series. It has not yet either been determined what relation the strata from which the Burgess and Grand Calumet specimens have been obtained bear to the Grenville limestone or to one another. The zone of Grenville limestone is in some places about 1500 feet thick, and it appears to be divided for considerable distances into two or three parts by very thick bands of gneiss. One of these occupies a position towards the lower part of the limestone, and may have a volume of between 100 and 200 feet. It is at the base of the limestone that the fossil occurs. This part of the zone is largely composed of great and small irregular masses of white crystalline pyroxene, some of them twenty yards in

length by four or five wide; and they appear to be confusedly placed one above another, with many ragged interstices and many smooth-worn, rounded, large and small pits and subcylindrical cavities, some of them pretty deep. The pyroxene, though it appears compact, presents a multitude of small spaces, consisting of carbonate of lime, and many of these show minute structures similar to that of the fossil. These masses of pyroxene may characterize a thickness of about 200 feet, and the interspaces among them are filled with a mixture of serpentine and carbonate of lime. In general a sheet of pure dark-green serpentine invests each mass of pyroxene, the thickness of the serpentine, varying from the sixteenth of an inch to several inches, rarely exceeding half a foot. This is followed in different spots by parallel, waving, irregularly alternating plates of carbonate of lime and serpentine, which become gradually finer as they recede from the pyroxene, and occasionally occupy a total thickness of five or six inches. These portions constitute the unbroken fossil, which may sometimes spread over an area of about a square foot, or perhaps more. Other parts, immediately on the outside of the sheet of serpentine, are occupied with about the same thickness of what appear to be the ruins of the fossil, broken up into a more or less granular mixture of calcspar and serpentine, the former still showing minute structure; and on the outside of the whole a similar mixture appears to have been swept by currents and eddies into rudely parallel and curving layers, the mixture becoming gradually more calcareous as it recedes from the pyroxene. Sometimes beds of limestone of several feet in thickness, with the green serpentine more or less aggregated into layers, and studded with isolated lumps of pyroxene, are irregularly interstratified in the mass of rock; and less frequently there are met with lenticular patches of sandstone, or granular quartzite, of a foot in thickness and several yards in diameter, holding in abundance small disseminated leaves of graphite.

The general character of the rock connected with the fossil produces the impression that it is a great Foraminiferal reef, in which the pyroxenic masses represent a more ancient portion, which having died, and having become much broken up and much worn into cavities and deep recesses, afforded a seat for a new growth of *Foraminifera*, represented by the calcareo-serpentinous part. This in its turn became broken up, leaving in some places uninjured portions of the general form. The main difference between this Foraminiferal reef and more recent coral-reefs seems to be that, while with the latter are usually associated many shells and other organic remains, in the more ancient one the only remains yet found are those of the animal which built the reef.

2. *On the* STRUCTURE *of certain* ORGANIC REMAINS *in the* LAURENTIAN LIMESTONES *of* CANADA. By J. W. DAWSON, LL.D., F.R.S., F.G.S., Principal of M'Gill University, Montreal.

[PLATES VI. & VII.]

AT the request of Sir William E. Logan, I have submitted to microscopic examination slices of certain peculiar laminated forms, consisting of alternate layers of carbonate of lime and serpentine, or of carbonate of lime and white pyroxene, found in the Laurentian Limestones of Canada, and regarded by Sir William as possibly fossils*. I have also examined slices of a number of limestones and serpentines from the Laurentian Series, not showing the external forms of these supposed fossils.

The slices were prepared by the lapidary of the Survey, and were carefully examined under ordinary and polarized light, with objectives made by Ross and Smith & Beck, and also with good French objectives.

The specimens first mentioned are masses, often several inches in diameter, presenting to the naked eye alternate laminæ of serpentine, or of pyroxene, and carbonate of lime. Their general aspect, as remarked by Sir W. E. Logan (Geology of Canada, 1863, p. 49), reminds the observer of that of the Silurian Corals of the genus *Stromatopora*, except that the laminæ diverge from and approach each other, and frequently anastomose or are connected by transverse septa.

Under the microscope the resemblance to *Stromatopora* is seen to be in general form merely, and no trace appears of the radiating cells characteristic of that genus. The laminæ of serpentine and pyroxene present no organic structure, and the latter mineral is highly crystalline. The laminæ of carbonate of lime, on the contrary, retain distinct traces of structures which cannot be of a crystalline or concretionary character. They constitute parallel or concentric partitions of variable thickness, enclosing flattened spaces or chambers frequently crossed by transverse plates or septa, in some places so numerous as to give a vesicular appearance, in others occurring only at rare intervals (Pl. VI., Pl. VII. fig. 1). The laminæ themselves are excavated on their sides into rounded pits, and are in some places traversed by canals, or contain secondary rounded cells apparently isolated (Pl. VII. fig. 2). In addition to these general appearances, the substance of the laminæ, where most perfectly preserved, is seen to present a fine granular structure, and to be penetrated by numerous minute tubuli, which are arranged in bundles of great beauty and complexity, diverging in sheaf-like forms, and in their finer extensions anastomosing so as to form a network (Pl. VII. figs. 3 *a*, 4). In transverse sections and under high powers, the tubuli are seen to be circular in outline and sharply defined (Pl. VII. fig. 5). In longitudinal sections they sometimes present a beaded or jointed appearance. Even where the tubular

* Canadian Naturalist and Geologist, 1859, p. 49.

structure is least perfectly preserved, traces of it can still be seen in most of the slices, though there are places in which the laminæ are perfectly compact, and perhaps were so originally.

Faithful delineations of these structures have been prepared by Mr. Horace Smith, the artist of the Survey, which will render them more intelligible than any verbal description.

With respect to the nature and probable origin of the appearances above described, I would make the following remarks:—

1. The serpentine and pyroxene which fill the cavities of the calcareous matter have no appearance of concretionary structure. On the contrary, their aspect is that of matter introduced by infiltration or as sediment, and filling spaces previously existing. In other words, the calcareous matter has not been moulded on the forms of the serpentine and augite, but these have filled spaces or chambers in a hard calcareous mass. This conclusion is further confirmed by the fact, to be referred to in the sequel, that the serpentine includes multitudes of minute foreign bodies, while the calcareous matter is uniform and homogeneous. It is also to be observed that small veins of carbonate of lime occasionally traverse the specimens, and, in their entire absence of structures other than crystalline, present a striking contrast to the supposed fossils.

2. Though the calcareous laminæ have in places a crystalline cleavage, their forms and structures have no relation to this. Their cells and canals are rounded, and have smooth walls, which are occasionally lined with films apparently of carbonaceous matter. Above all, the minute tubuli are different from anything likely to occur in merely crystalline calcspar. While in such rocks little importance might be attached to external forms simulating the appearances of corals, sponges, or other organisms, these delicate internal structures have a much higher claim to attention. Nor is there any improbability in the preservation of such minute parts in rocks so highly crystalline, since it is a circumstance of frequent occurrence in the microscopic examination of fossils that the finest structures are visible in specimens in which the general form and the arrangement of parts have been entirely obliterated. It is also to be observed that the structure of the calcareous laminæ is the same, whether the intervening spaces are filled with serpentine or with pyroxene.

3. The structures above described are not merely definite and uniform, but they are of a kind proper to animal organisms, and more especially to one particular type of animal life, as likely as any other to occur under such circumstances; I refer to that of the Rhizopods of the order *Foraminifera*. The most important point of difference is in the great size and compact habit of growth of the specimens in question; but there seems no good reason to maintain that *Foraminifera* must necessarily be of small size, more especially since forms of considerable magnitude referred to this type are known in the Lower Silurian. Prof. Hall has described specimens of *Receptaculites* 12 inches in diameter; and the fossils from the calciferous formation of Labrador, referred by Mr. Billings to the genus *Archæocyathus*, are examples of *Protozoa* with calcareous skeletons, scarcely inferior

in their massive style of growth to the forms now under consideration.

These reasons are, I think, sufficient to justify me in regarding these remarkable structures as truly organic, and in searching for their nearest allies among the *Foraminifera*.

Supposing then that the spaces between the calcareous laminæ, as well as the canals and tubuli traversing their substance, were once filled with the sarcode body of a Rhizopod, comparisons with modern forms at once suggest themselves.

From the polished specimens in the Museum of the Canadian Geological Survey, it appears certain that these bodies were sessile by a broad base, and grew by the addition of successive layers of chambers separated by calcareous laminæ, but communicating with each other by canals or septal orifices sparsely and irregularly distributed. Small specimens have thus much the aspect of the modern genera *Carpenteria* and *Polytrema*. Like the first of these genera, there would also seem to have been a tendency to leave in the midst of the structure a large central canal, or deep funnel-shaped or cylindrical opening, for communication with the sea-water. Where the laminæ coalesce, and the structure becomes more vesicular, it assumes the "acervuline" character seen in such modern forms as *Nubecularia*.

Still the magnitude of these fossils is enormous when compared with the species of the genera above named; and from the specimens in the larger slabs from Grenville, in the Museum of the Canadian Survey, it would seem that these organisms grew in groups which ultimately coalesced and formed large masses penetrated by deep irregular canals, and that they continued to grow at the surface while the lower parts became dead and were filled up with infiltrated matter or sediment. In short, we have to imagine an organism having the habit of growth of *Carpenteria*, but attaining to an enormous size, and by the aggregation of individuals assuming the aspect of a coral-reef.

Mr. Billings has described two remarkable species from the Calciferous formation at Mingan, referred by him to the new genus *Archæocyathus*, which he places, with doubt, among *Protozoa*. If, as I believe, correctly referred to this group, their calcareous-chambered skeletons would place them with *Foraminifera* rather than with Sponges. The mode of growth of *Archæocyathus* is cylindrical or inverted conical, with a hollow axis. In one of the species, *A. Minganensis*, this hollow cylinder is very wide, and the chambers are arranged in a radiating manner. In the other, *A. atlanticus*, the central canal is narrower, and the chambers have thick walls and are more irregularly disposed. These fossils, in the general arrangement of their parts, appear like gigantic representatives of *Nubecularia* and *Dactylopora*, though different in details. They are evidently generically distinct from the Laurentian fossils; but if, as I think probable, calcareous Rhizopods, they resemble the specimens now under consideration in the development of such structures into coral-like forms and dimensions, and this at an early, if less remote, geological period.

The complicated systems of tubuli in the Laurentian fossils indicate, however, a more complex structure than that of any of the forms mentioned above. I have carefully compared these with the similar structures in the "supplementary skeleton" (or the shell-substance that carries the vascular system) of *Calcarina* and other forms*, and can detect no difference except in the somewhat coarser texture of the tubuli in the Laurentian specimens. It accords well with the great dimensions of these, that they should thus thicken their walls with an extensive deposit of tubulated calcareous matter; and, from the frequency of the bundles of tubuli, as well as the thickness of the partitions, I have no doubt all the successive walls as they were formed were thickened in this manner, just as in so many of the higher genera of more modern *Foraminifera*.

It is proper to add that no spicules, or other structures indicating affinity to the Sponges, have been detected in any of the specimens.

As it is convenient to have a name to designate these forms, I would propose that of *Eozoön*, which will be specially appropriate to what seems to be the characteristic fossil of a group of rocks which must now be named *Eozoic* rather than Azoic. For the species above described, the specific name of *Canadense* has been proposed. It may be distinguished by the following characters:—

Eozoön Canadense, gen. et spec. nov. Pls. VI. & VII.†

General form.—Massive, in large sessile patches or irregular cylinders, growing at the surface by the addition of successive laminæ.

Internal structure.—Chambers large, flattened, irregular, with numerous rounded extensions, and separated by walls of variable thickness, which are penetrated by septal orifices irregularly disposed. Thicker parts of the walls with bundles of fine branching tubuli.

These characters refer specially to the specimens from Grenville and the Calumet. There are others from Perth, Canada West, which show more regular laminæ, and in which the tubuli have not yet been observed; and a specimen from Burgess, Canada West, contains some fragments of laminæ which exhibit, on one side, a series of fine parallel tubuli like those of *Nummulina*. These specimens may indicate distinct species; but, on the other hand, their peculiarities may depend on different states of preservation.

With respect to this last point, it may be remarked that some of the specimens from Grenville and the Calumet show the structures of the laminæ with nearly equal distinctness whether the chambers have been filled with serpentine or pyroxene, and that even the minute tubuli are penetrated and filled with these minerals. On the other

* I desire to express my obligations to the invaluable memoirs of Dr. Carpenter on the *Foraminifera*, in the 'Transactions' of the Royal Society and in the publications of the Ray Society, and without which it would have been impossible satisfactorily to investigate the structure and affinities of *Eozoön*. I have also to acknowledge the kindness of Dr. Carpenter in furnishing me with specimens of some of the forms described in his works.

† Plates VIII. & IX., illustrating the following paper by Dr. Carpenter, further elucidate the structure of *Eozoön*.—Ed.

hand. There are large specimens in the collection of the Canadian Survey, in which the lower and older parts of the masses of *Eozoön* are mineralized with pyroxene, and have to a great extent lost the perfection of structure which characterizes the more superficial parts of the same masses, in which the chambers have been filled with a light-green serpentine. Dr. Sterry Hunt has directed his attention to the conditions of deposit of these minerals, and will, I have no doubt, be able satisfactorily to explain the manner in which they may have been introduced into the chambers of the fossils without destroying the texture of the latter.

It is due to Dr. Sterry Hunt to state that, as far back as 1858, in a paper published in the Quarterly Journal of the Geological Society*, he insisted on certain chemical characters of the Laurentian beds as affording "evidence of the existence of organic life at the time of the deposition of these old crystalline rocks," and that he has zealously aided in the present researches.

I may also state that Mr. Billings, the palæontologist of the Survey, has joined in the request that I should undertake the examination and description of the specimens, as being more specially a subject of microscopical investigation.

Before concluding this part of the subject, it is proper to observe that the structures above described can be made out only by the careful study of numerous slices, and in some instances only with polarized light. Even in the more perfect specimens of *Eozoön*, as those accustomed to such researches will readily understand, the accidents of good preservation and the cutting of the slices in the proper place and direction must conspire in order to a clear definition of the more minute structures.

It is also to be observed that the specimens present numerous remarkable microscopic appearances, depending on crystallization and concretionary action, which must not be confounded with organic structure. It would be out of place to give any detailed description of them here, but it is necessary to caution observers unaccustomed to the examination of mineral substances under the microscope, as to their occurrence. I may also mention that the serpentine presents many curious varieties of structure, especially when associated with apatite, pyroxene, and other minerals, and that it affords magnificent objects under polarized light, when reduced to sufficiently thin slices.

In connexion with these remarkable remains, it appeared desirable to ascertain, if possible, what share these or other organic structures may have had in the accumulation of the limestones of the Laurentian series. Specimens were therefore selected by Sir W. E. Logan, and slices were prepared under his direction. On microscopic examination, a number of these were found to exhibit merely a granular aggregation of crystals, occasionally with particles of graphite and other foreign minerals, or a laminated mixture of calcareous and other matters, in the manner of some more modern sedimentary

* Vol. xv. p. 493.

limestones. Others, however, were evidently made up almost entirely of fragments of *Eozoön*, or of mixtures of these with other calcareous and carbonaceous fragments which afford more or less evidence of organic origin. The contents of these organic limestones may be considered under the following heads:—(1) Remains of *Eozoön*; (2) Other calcareous bodies probably organic; (3) Objects imbedded in the serpentine; (4) Carbonaceous matters; (5) Perforations or worm-burrows.

1. The more perfect specimens of *Eozoön* do not constitute the mass of any of the larger specimens in the collection of the Survey; but considerable portions of some of them are made up of material of similar minute structure, destitute of lamination and irregularly arranged. Some of this material gives the impression that there may have been organisms similar to *Eozoön*, but growing in an irregular or "acervuline" manner without lamination. Of this, however, I cannot be certain, and on the other hand there is distinct evidence of the aggregation of fragments of *Eozoön* in some of these specimens. In some they constitute the greater part of the mass. In others they are imbedded in calcareous matter of a different character, or in serpentine or granular pyroxene. In most of the specimens the cells of the fossils are more or less filled with these minerals, and in some instances it would appear that the calcareous matter of fragments of *Eozoön* has been in part replaced by serpentine.

2. Intermixed with the fragments of *Eozoön* above referred to, are other calcareous matters apparently fragmentary. They are of various angular and rounded forms, and present several kinds of structure. The most frequent of these is a strong lamination, varying in direction according to the position of the fragments, but corresponding, as far as can be ascertained, with the diagonal of the rhombohedral cleavage. This structure, though crystalline, is highly characteristic of Crinoidal remains when preserved in altered limestones. The more dense parts of *Eozoön*, destitute of tubuli, also sometimes show this structure, though less distinctly.

Other fragments are compact and structureless, or show only a fine granular appearance; and these sometimes include grains, patches, or fibres of graphite. In Silurian limestones, fragments of corals and shells which have been partially infiltrated with bituminous matter show a structure like this. On comparison with altered organic limestones of the Silurian system, these appearances would indicate that, in addition to the débris of *Eozoön*, other calcareous structures, more like those of Crinoids, Corals, and Shells, have contributed to the formation of the Laurentian limestones.

3. In the serpentine filling the chambers of a large portion of *Eozoön* from Burgess, C. W., there are numerous small pieces of foreign matter, and the serpentine itself is laminated, indicating its sedimentary nature. Some of the included fragments appear to be carbonaceous, others calcareous; but no distinct organic structure can be detected in them. There are, however, in the serpentine many minute rounded grains of a bright-green siliceous colour, re-

sembling greensand-concretions; and the manner in which these are occasionally arranged in lines and groups suggests the supposition that they may possibly be casts of the interior of minute Foraminiferal shells. They may, however, be concretionary in their origin.

4. In some of the Laurentian limestones submitted to me by Sir W. E. Logan, and in others which I collected some years ago at Madoc, Canada West, there are fibres and granules of carbonaceous matter, which do not conform to the crystalline structure, and present forms quite similar to those which in more modern limestones result from the decomposition of Algæ. Though retaining mere traces of organic structure, no doubt would be entertained as to their vegetable origin if they were found in fossiliferous limestones.

5. A specimen of impure limestone from Madoc, in the collection of the Canadian Geological Survey, which seems from its structure to have been a finely laminated sediment, shows perforations of various sizes, somewhat scolloped at the sides, and filled with grains of rounded siliceous sand. In my own collection there are specimens of micaceous slate from the same region, with indications on their weathered surfaces of similar rounded perforations, having the aspect of *Scolithus*, or of worm-burrows.

I would observe, in conclusion, that the researches detailed in this paper must be regarded as merely an introduction to a most interesting and promising field of research. The specimens to which I had access were for the most part collected by the explorers of the Survey merely as rocks, and without any view to the possible existence of fossils in them. It may be hoped, therefore, that other and more perfect specimens may reward a careful search in the localities from which those now described have been obtained. Further, though the abundance and wide distribution of *Eozoön*, and the important part it seems to have acted in the accumulation of limestone, indicate that it was one of the most prevalent forms of animal existence in the seas of the Laurentian period, they do not imply the non-existence of other organic beings. On the contrary, independently of the indications afforded by the limestones themselves, it is evident that in order to the existence and growth of these large Rhizopods, the waters must have swarmed with more minute animal or vegetable organisms on which they could subsist. On the other hand, though this is a less certain inference, the dense calcareous skeleton of *Eozoön* may indicate that it also was liable to the attacks of animal enemies. It is also possible that the growth of *Eozoön*, or the deposition of the serpentine and pyroxene in which its remains have been preserved, or both, may have been connected with certain oceanic depths and conditions, and that we have as yet revealed to us the life of only certain stations in the Laurentian seas.

Whatever conjectures we may form on these more problematic points, the observations above detailed appear to establish the following conclusions:—First, that in the Laurentian period, as in subsequent geological epochs, the Rhizopods were important agents in the accumulation of beds of limestone; and, secondly, that in this early period these low forms of animal life attained to a development,

in point of magnitude and complexity, unexampled, in so far as yet known, in the succeeding ages of the earth's history. This early culmination of the Rhizopods is in accordance with one of the great laws of the succession of living beings ascertained from the study of the introduction and progress of other groups; and, should it prove that these great Protozoans were really the dominant type of animals in the Laurentian period, this fact might be regarded as an indication that in these ancient rocks we may actually have the records of the first appearance of animal life on our planet.

Since the above was written, thick slices of *Eozoön* from Grenville have been prepared, and submitted to the action of hydrochloric acid until the carbonate of lime was removed. The serpentine then remains as a cast of the interior of the chambers, showing the form of their original sarcode-contents. The minute tubuli are found also to have been filled with a substance insoluble in the acid, so that casts of these also remain in great perfection, and allow their general distribution to be much better seen than in the transparent slices previously prepared. These interesting preparations establish the following additional structural points:—

1. That the whole mass of sarcode throughout the organism was continuous, the apparently detached secondary chambers being, as I had previously suspected, connected with the larger chambers by canals filled with sarcode.

2. That some of the irregular portions without lamination are not fragmentary, but due to the acervuline growth of the animal; and that this irregularity has been produced in part by the formation of projecting patches of "supplementary skeleton," penetrated by beautiful systems of tubuli. These groups of tubuli are in some places very regular, and have in their axes cylinders of compact calcareous matter. Some parts of the specimens present arrangements of this kind as symmetrical as in any modern Foraminiferal shell.

3. That all except the very thinnest portions of the walls of the chambers present traces, more or less distinct, of a tubular structure.

4. These facts place in more strong contrast the structure of the regularly laminated specimens from Burgess, which do not show tubuli, and that of the Grenville specimens, less regularly laminated and tubulous throughout. I hesitate, however, to regard these as distinct species, in consequence of the intermediate characters presented by specimens from the Calumet, which are regularly laminated like those of Burgess, and tubulous like those of Grenville. It is possible that in the Burgess specimens tubuli originally present have been obliterated; and in organisms of this grade, more or less altered by the processes of fossilization, large suites of specimens should be compared before attempting to establish specific distinctions.

Some additional specimens, from a block consisting principally of serpentine, differ from the ordinary Grenville specimens in the more highly crystalline character of the calcareous spar and serpentine, in the development of certain minute dendritic crystallizations, and in the apparent compression and distortion of the fossils. These ap-

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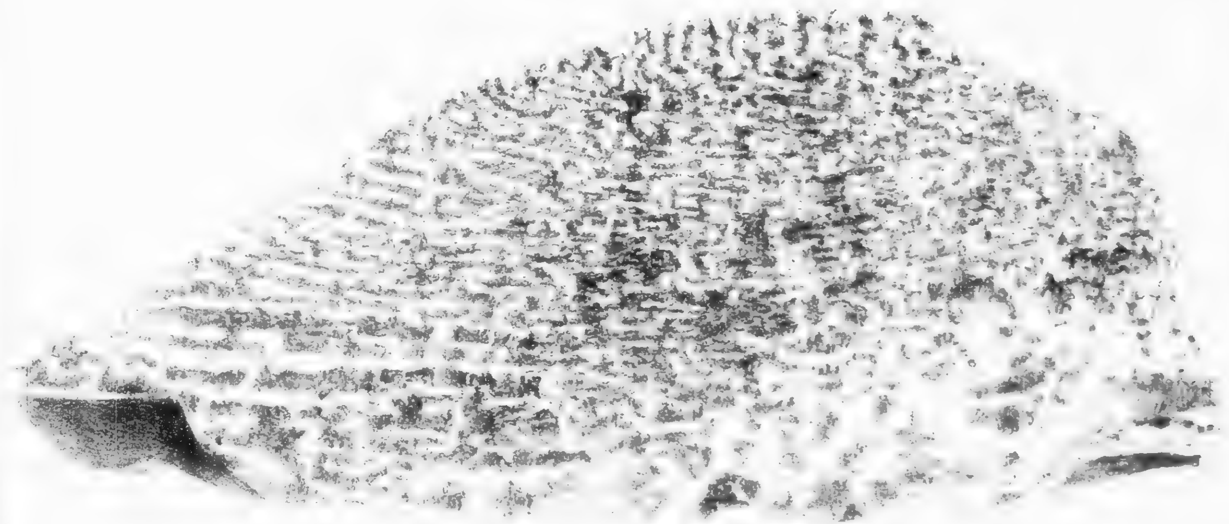

EOZOON CANADENSE, Dawson.

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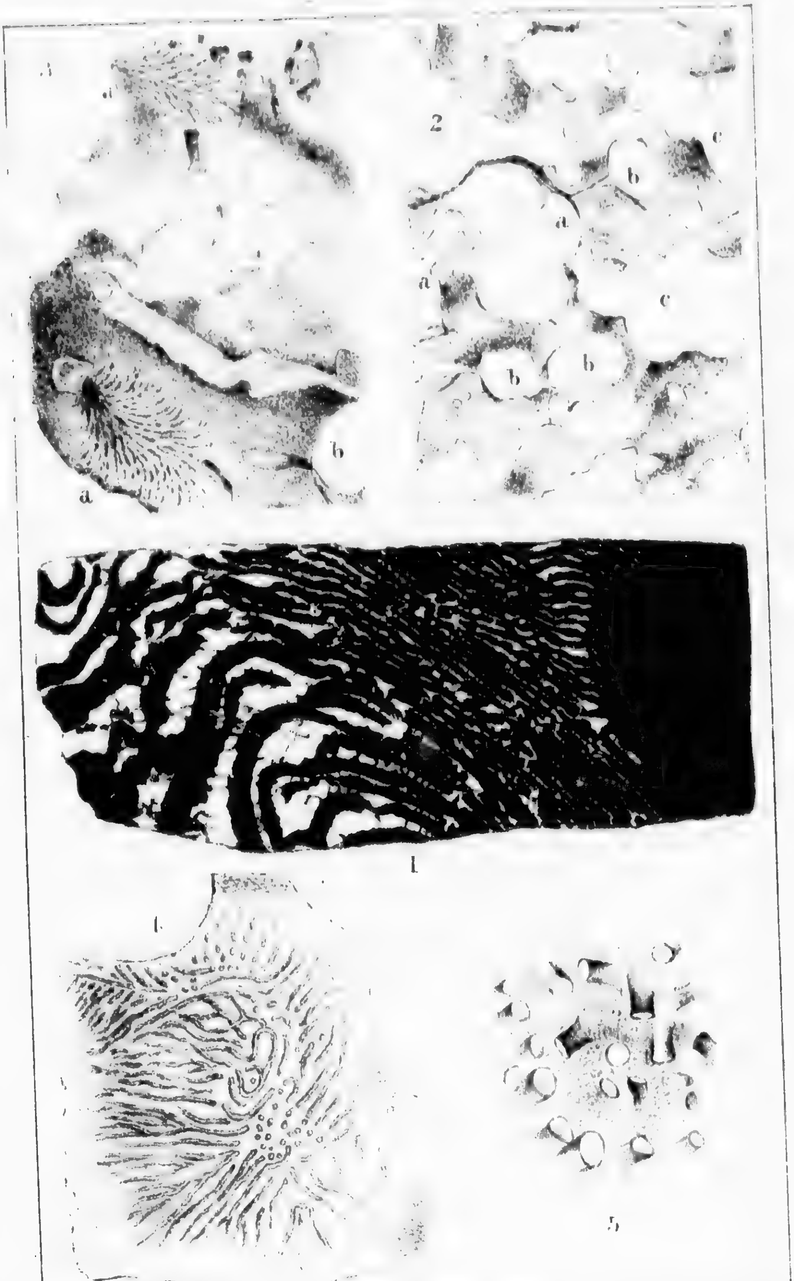

G. West lith. M & N. Hanhart, Imp.

EOZOON CANADENSE, *Dawson*.

pearances I regard as due to the mode of preservation rather than to any original differences, certain portions less altered than the others presenting the ordinary typical characters.

Two slices of limestone from the British Islands, and supposed to be Laurentian, have been compared with the Canadian limestones above noticed. One is a serpentine marble from Tyree. It appears to be fragmental, like some of the Laurentian limestones of Canada, and may contain fragments of *Eozoön*. The other is from Iona (?). It presents what I regard as traces of organic structure, but not, in so far as can be made out, of the character of *Eozoön*. Both of these limestones deserve careful microscopic examination.

EXPLANATION OF PLATES VI. & VII.

Illustrating the Structure of Eozoön.

PLATE VI.

Specimen from Grand Calumet. Natural size. The white layers are carbonate of lime; the dark layers are whitish pyroxene.

PLATE VII.

Fig. 1. Specimen from Burgess. Natural size. The white layers are dolomite; the black layers are dark-green loganite.
2. Transverse section of *Eozoön* from Grenville, magnified 25 diameters: (*a*) tubuli; (*b*) septal orifices, &c.; (*c*) large chambers.
3. Horizontal section of *Eozoön* from Grenville, magnified 25 diameters: (*a*) systems of tubuli; (*b*) secondary chamber.
4. One of the systems of tubuli cut transversely, magnified 100 diameters.
5. Part of a system of tubuli cut transversely, magnified 200 diameters.

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3. ADDITIONAL NOTE *on the* STRUCTURE *and* AFFINITIES *of* EOZOÖN CANADENSE. By W. B. CARPENTER, M.D., F.R.S., F.G.S.

[In a Letter to Sir William E. Logan, LL.D., F.R.S., F.G.S.]

[PLATES VIII. & IX.]

THE careful examination which I have made—in accordance with the request you were good enough to convey to me from Dr. Dawson, and to second on your own part—into the structure of the very extraordinary fossil which you have brought from the Laurentian rocks of Canada*, enables me most unhesitatingly to confirm the sagacious determination of Dr. Dawson as to its Rhizopod characters and Foraminiferal affinities, and at the same time furnishes new evidence of no small value in support of that determination. In this examination I have had the advantage of a series of *sections* of the fossil much superior to those submitted to Dr. Dawson; and also of a large series of *decalcified specimens*, of which Dr. Dawson had only the opportunity of seeing a few examples after his memoir had been written. These last are peculiarly instructive; since, in conse-

* The specimens submitted to Dr. Carpenter were taken from a block of Eozoön rock, obtained in the Petite Nation Seigniory, too late to afford Dr. Dawson an opportunity of examination. They are from the same horizon as the Grenville specimens.—W. E. L.

quence of the complete infiltration of the chambers and canals, originally occupied by the sarcode-body of the animal, by mineral matter insoluble in dilute nitric acid, the removal of the calcareous shell brings into view not only the internal casts of the chambers, but also casts of the interior of the "canal-system" of the "intermediate" or "supplemental skeleton," and even casts of the interior of the very fine parallel tubuli which traverse the proper walls of the chambers. And, as I have remarked elsewhere *, "such casts place before us far more exact representations of the configuration of the animal body and of the connexions of its different parts, than we could obtain even from living specimens by dissolving-away their shells with acid; its several portions being disposed to heap themselves together in a mass when they lose the support of the calcareous skeleton."

The additional opportunities I have thus enjoyed will be found, I believe, to account satisfactorily for the differences to be observed between Dr. Dawson's account of the *Eozoön* and my own. Had I been obliged to form my conclusions respecting its structure only from the specimens submitted to Dr. Dawson, I should very probably have seen no reason for any but the most complete accordance with his description: while if Dr. Dawson had enjoyed the advantage of examining the entire series of preparations which have come under my own observation, I feel confident that he would have anticipated the corrections and additions which I now offer.

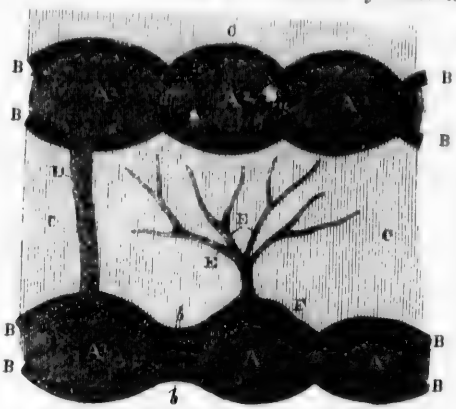
Although the *general plan of growth* described by Dr. Dawson, and exhibited in his photographs of vertical sections of the fossil (Pl. VI., Pl. VII. fig. 1), is undoubtedly that which is typical of *Eozoön*, yet I find that the *acervuline* mode of growth, also mentioned by Dr. Dawson, very frequently takes its place in the more superficial parts, where the chambers, which are arranged in regular tiers in the laminated portions (Pl. VIII. fig. 1), are heaped one upon another without any regularity, as is particularly well shown in some decalcified specimens which I have myself prepared from the slices last put into my hands (Pl. IX. fig. 2). I see no indication that this departure from the normal type of structure has resulted from an injury; the transition from the regular to the irregular mode of increase not being abrupt, but gradual. Nor should I be disposed to regard it as a monstrosity; since there are many other *Foraminifera* in which an originally definite plan of growth gives place in a later stage to a like acervuline piling-up of chambers.

In regard to the *form and relations of the chambers*, I have little to add to Dr. Dawson's description. The evidence afforded by their internal casts (Pl. IX. fig. 1) concurs with that of sections, in showing that the segments of the sarcode-body, by whose aggregation each layer was constituted, were but very incompletely divided by shelly partitions; this incomplete separation (as Dr. Dawson has pointed out) having its parallel in that of the secondary chambers in *Carpenteria*. But I have occasionally met with instances in which the

* Introduction to the Study of the Foraminifera, p. 10.

separation of the chambers has been as complete as it is in Foraminifera generally; and the communication between them is then established by several narrow passages (Pl. VIII. fig. 2) exactly corresponding with those which I have described and figured in *Cycloclypeus* *.

Diagram illustrating the Structure of Eozoön.



A^1, A^1, A^1. Three chambers of one layer, communicating with each other directly at *a*, and by three passages through a shelly partition at *b*.
A^2, A^2, A^2. Three chambers of a more superficial layer.
B, B, B. Proper wall of the chambers, composed of finely-tubular shell-substance.
C, C, C. Intermediate or supplemental skeleton, traversed by D, D, a stolon of communication between two chambers of different layers, and by E, E, canal-system originating in the lacunar space F.

The *mode in which each successive layer originates from the one which has preceded it*, is a question to which my attention has been a good deal directed; but I do not as yet feel confident that I have been able to elucidate it completely. There is certainly no *regular* system of apertures for the passage of *stolons* giving origin to new segments, such as are found in all ordinary Polythalamous Foraminifera, whether their type of growth be rectilinear, spiral, or cyclical; and I am disposed to believe that where one layer is separated from another by nothing else than the proper walls of the chambers,—which (as I shall presently show) are traversed by multitudes of minute tubuli giving passage to pseudopodia,—the coalescence of these pseudopodia on the external surface would suffice to lay the foundation of a new layer of sarcodic segments. But where an *intermediate* or *supplemental skeleton*, consisting of a thick layer of solid calcareous shell, has been deposited between two successive layers, it is obvious that the animal body contained in the lower layer of chambers must be completely cut off from that which occupies the upper, unless some special provision exist for their mutual

* *Op. cit.* p. 294.

communication. Such a provision I believe to have been made by the extension of bands of sarcode, through canals left in the intermediate skeleton, from the lower to the upper tier of chambers. For in such sections as happen to have traversed thick deposits of the intermediate skeleton, there are generally found passages distinguished from those of the ordinary "canal-system" by their broad flat form, their great transverse diameter, and their non-ramification. One of these passages I have distinctly traced to a chamber, with the cavity of which it communicated through two or three apertures in its proper wall (Pl. VIII. fig. 3 *c*); and I think it likely that I should have been able to trace it at its other extremity into a chamber of the superjacent tier, had not the plane of the section passed out of its course. Riband-like casts of these passages are often to be seen in decalcified specimens, traversing the void spaces left by the removal of the thickest layers of the intermediate skeleton (Pl. IX. fig. 3).

But the organization of a new layer seems to have not unfrequently taken place in a much more considerable extension of the sarcode-body of the pre-formed layer; which either folded back its margin over the surface already consolidated (in a manner somewhat like that in which the mantle of a *Cypræa* doubles back to deposit the final surface-layer of its shell), or sent upwards wall-like lamellæ, sometimes of very limited extent, but not unfrequently of considerable length, which, after traversing the substance of the shell like trap-dykes in a bed of sandstone, spread themselves out over its surface. Such, at least, are the only interpretations I can put upon the appearances presented by decalcified specimens. For, on the one hand, it is frequently to be observed that two bands of serpentine (or other infiltrated mineral) which represent two layers of the original sarcode-body of the animal, approximate each other in some part of their course, and come into complete continuity; so that the upper layer would seem at that part to have had its origin in the lower. Again, even where these bands are most widely separated, we find that they are commonly held together by vertical lamellæ of the same material, sometimes forming mere tongues, but often running to a considerable length. That these lamellæ have not been formed by mineral infiltration into accidental fissures in the shell, but represent corresponding extensions of the sarcode-body, seems to me to be indicated not merely by the characters of their surface, but also by the fact that portions of the canal-system may be occasionally traced into connexion with them.

Although Dr. Dawson has noticed that some parts of the sections which he examined present the fine tubulation characteristic of the shells of the *Nummuline* Foraminifera, he does not seem to have recognized the fact, which the sections placed in my hands have enabled me most satisfactorily to determine,—that *the proper walls of the chambers everywhere present the fine tubulation of the Nummuline shell* (Pl. VIII. figs. 3, 4), a point of the highest importance in the determination of the affinities of *Eozoön*. This tubulation, although not seen with the clearness with which it is to be discerned in *recent*

examples of the Nummuline type, is here far better displayed than it is in the majority of *fossil* Nummulites, in which the tubuli have been filled up by the infiltration of calcareous matter, rendering the shell-substance nearly homogeneous. In *Eozoön* these tubuli have been filled up by the infiltration of a mineral different from that of which the shell is composed, and therefore not coalescing with it; and the tubular structure is consequently much more satisfactorily distinguishable. In decalcified specimens, the free margins of the casts of the chambers are often seen to be bordered with a delicate white glistening fringe; and when this fringe is examined with a sufficient magnifying power, it is seen to be made up of a multitude of extremely delicate *aciculi*, standing side by side like the fibres of asbestos (Pl. IX. fig. 4). These, it is obvious, are the internal casts of the fine tubuli which perforated the proper wall of the chambers, passing direct from its inner to its outer surface; and their presence in this situation affords the most satisfactory confirmation of the evidence of that tubulation afforded by thin sections of the shell-wall.

The successive layers, each having its own proper wall, are often superposed one upon another without the intervention of any *supplemental* or *intermediate skeleton*, such as presents itself in all the more massive forms of the Nummuline series; but a deposit of this form of shell-substance, readily distinguishable by its homogeneousness from the finely tubular shell immediately investing the segments of the sarcode-body, is the source of the great thickening which the calcareous zones often present in vertical sections of *Eozoön*. The presence of this "intermediate skeleton" has been correctly indicated by Dr. Dawson; but he does not seem to have clearly differentiated it from the proper wall of the chambers. All the tubuli which he has described belong to that *canal-system*, which, as I have shown*, is limited in its distribution to the "intermediate skeleton," and is expressly destined to supply a channel for its nutrition and augmentation. Of this "canal-system," which presents most remarkable varieties in dimensions and distribution, we learn more from the *casts* presented by decalcified specimens, than from *sections* which only exhibit such parts of it as their plane may happen to traverse. Illustrations from both sources, giving a more complete representation of it than Dr. Dawson's figures afford, have been prepared from the additional specimens placed in my hands (Pl. VIII. fig. 5, Pl. IX. fig. 5).

It does not appear to me that the "canal-system" takes its origin directly from the cavity of the chambers. On the contrary, I believe that, as in *Calcarina* (which Dr. Dawson has correctly referred to as presenting the nearest parallel to it among recent *Foraminifera*), they originate in lacunar spaces on the outside of the proper walls of the chambers, into which the tubuli of those walls open externally; and that the extensions of the sarcode-body which occupied them were formed by the coalescence of the pseudopodia issuing from those tubuli†.

* *Op. cit.* pp. 50, 51. † *Op. cit.* p. 221.

It seems to me worthy of special notice, that the "canal-system," wherever displayed in transparent sections, is distinguished by a yellowish-brown coloration, so exactly resembling that which I have observed in the canal-system of recent *Foraminifera* (as *Polystomella* and *Calcarina*) in which there were remains of the sarcode-body, that I cannot but believe the infiltrating mineral to have been dyed by the remains of sarcode still existing in the canals of *Eozoön* at the time of its consolidation. If this be the case, the preservation of this colour seems to indicate that no considerable metamorphic action has been exerted upon the rock in which this fossil occurs. And I should draw the same inference from the fact that the organic structure of the shell is in many instances even more completely preserved than it usually is in the Nummulites and other *Foraminifera* of the Nummulitic limestone of the early Tertiaries.

To sum up,—That the *Eozoön* finds its proper place in the Foraminiferal series, I conceive to be conclusively proved by its accordance with the great types of that series in all the essential characters of organization,—namely, the structure of the shell forming the proper wall of the chambers, in which it agrees precisely with *Nummulina* and its allies; the presence of an "intermediate skeleton" and an elaborate "canal-system," the disposition of which reminds us most of *Calcarina*; a mode of communication of the chambers when they are most completely separated, which has its exact parallel in *Cycloclypeus*; and an ordinary want of completeness of separation between the chambers, corresponding with that which is characteristic of *Carpenteria*.

There is no other group of the Animal Kingdom to which *Eozoön* presents the slightest structural resemblance; and to the suggestion that it may have been of kin to *Nullipore* I can offer the most distinct negative reply, having many years ago carefully studied the structure of that stony *Alga*, with which that of *Eozoön* has nothing whatever in common.

The objections which not unnaturally occur to those familiar with only the ordinary forms of *Foraminifera*, as to the admission of *Eozoön* into the series, do not appear to me of any force. These have reference in the first place to the great *size* of the organism; and in the second, to its exceptional *mode of growth*.

1. It must be borne in mind that all the *Foraminifera* normally increase by the continuous gemmation of new segments from those previously formed; and that we have, in the existing types, the greatest diversities in the extent to which this gemmation may proceed. Thus in the *Globigerinæ*, whose shells cover to an unknown thickness the sea-bottom of all that portion of the Atlantic Ocean which is traversed by the Gulf-stream, only *eight* or *ten* segments are ordinarily produced by continuous gemmation; and if new segments are developed from the last of these, they detach themselves so as to lay the foundation of independent *Globigerinæ*. On the other hand, in *Cycloclypeus*, which is a discoidal structure attaining $2\frac{1}{4}$ inches in diameter, the number of segments formed by continuous gemmation must be many thousand. Again, the *Receptaculites* of the Canadian

Silurian rocks, shown by Mr. Salter's drawings* to be a gigantic Orbitolite, attains a diameter of 12 inches; and if this were to increase by vertical as well as by horizontal gemmation (after the manner of *Tinoporus* or *Orbitoides*) so that one discoidal layer would be piled on another, it would form a mass equalling *Eozoön* in its ordinary dimensions. To say, therefore, that *Eozoön* cannot belong to the *Foraminifera* on account of its gigantic size, is much as if a Botanist who had only studied plants and shrubs were to refuse to admit a tree into the same category. The very same continuous gemmation which has produced an *Eozoön* would produce an equal mass of independent *Globigerinæ*, if, after eight or ten repetitions of the process, the new segments were to detach themselves.

It is to be remembered, moreover, that the largest masses of *Sponges* are formed by continuous gemmation from an original Rhizopod segment; and that there is no *à priori* reason why a *Foraminiferal* organism should not attain the same dimensions as a *Poriferal*,—the intimate relationship of the two groups, notwithstanding the difference between their skeletons, being unquestionable.

2. The difficulty arising from the Zoophytic plan of growth of *Eozoön* is at once disposed of by the fact that we have in the recent *Polytrema* (as I have shown, *op. cit.* p. 235) an organism nearly allied in all essential points of structure to *Rotalia*, yet no less aberrant in its plan of growth, having been ranked by Lamarck among the *Millepores*. And it appears to me that *Eozoön* takes its place quite as naturally in the *Nummuline* series as *Polytrema* in the *Rotaline*. As we are led from the typical *Rotalia*, through the less regular *Planorbulina*, to *Tinoporus*, in which the chambers are piled up vertically, as well as multiplied horizontally, and thence pass by an easy gradation to *Polytrema*, in which all regularity of external form is lost, so may we pass from the typical *Operculina* or *Nummulina*, through *Heterostegina* and *Cycloclypeus*, to *Orbitoides*, in which, as in *Tinoporus*, the chambers multiply, both by horizontal and by vertical gemmation; and from *Orbitoides* to *Eozoön* the transition is scarcely more abrupt than from *Tinoporus* to *Polytrema*.

The general acceptance, by the most competent judges, of my views respecting the *primary* value of the characters furnished by the *intimate structure of the shell*, and *the very subordinate* value of *plan of growth*, in the determination of the affinities of Foraminifera, renders it unnecessary that I should dwell further on my reasons for unhesitatingly affirming the Nummuline affinities of *Eozoön* from the microscopic appearances presented by the proper wall of its chambers, notwithstanding its very aberrant peculiarities; and I cannot but feel it to be a feature of peculiar interest in geological inquiry, that the true relations of by far the earliest fossil yet known should be determinable by the comparison of a portion which the smallest pin's head would cover, with organisms at present existing.

I need not assure you of the pleasure which it has afforded me to

* First Decade of Canadian Fossils, pl. x.

be able to cooperate with Dr. Dawson and yourself in this development of my previous researches; but I may venture to add the anticipation that the discovery of *Eozoön* is the first of many discoveries in the Laurentian series, which will vastly add to our knowledge of the primæval life of our globe. And I am strongly inclined also to concur in the belief expressed by Dr. Dawson in a private letter to myself, that a more thorough examination of some of the Silurian fossils (such as *Stromatopora*) hitherto ranked among *Corals* and *Sponges*, will prove that they are really, like *Eozoön* and *Receptaculites*, gigantic *Foraminifera*.

EXPLANATION OF PLATES VIII. & IX.

Illustrating the Structure and Affinities of Eozoön.

Plate VIII.

[The figures in this plate are all taken from *transparent sections* of specimens in which the original Shell has been well preserved, and its minutest cavities infiltrated with Serpentine.]

Fig. 1. Vertical section of regularly stratified portion, showing the ordinarily continuous connexion of the chambers of each stratum: magnified 10 diameters.

2. Occasional mode of communication between two distinct chambers of the same series: magnified 40 diameters.

3. Portions of two chambers of different layers, showing at *a*, *a* the proper walls of their chambers, at *b*, *b* the intermediate skeleton, and at *c*, *c* a stoloniferous passage: magnified 25 diameters.

4. Portions of the proper wall of the chambers, showing its Nummuline tubulation, as seen at *a* in longitudinal, and at *b* in transverse section: magnified 100 diameters.

5. Sections of intermediate skeleton, showing portions of canal-system of different dimensions,—*a*, large, *b*, medium, *c*, small: magnified 25 diameters.

Plate IX.

[The figures in this plate are all taken from decalcified specimens, and represent the appearances presented by the *internal casts* of the cavities, tubes, &c., as seen by reflected light.]

Fig. 1. Portion of chambered layer, showing the continuous connexion of its segments: magnified 10 diameters.

2. Portion of acervuline structure, showing the irregular connexions of its segments: magnified 10 diameters.

3. Casts of flattened stolons communicating between successive layers of chambers: magnified 25 diameters.

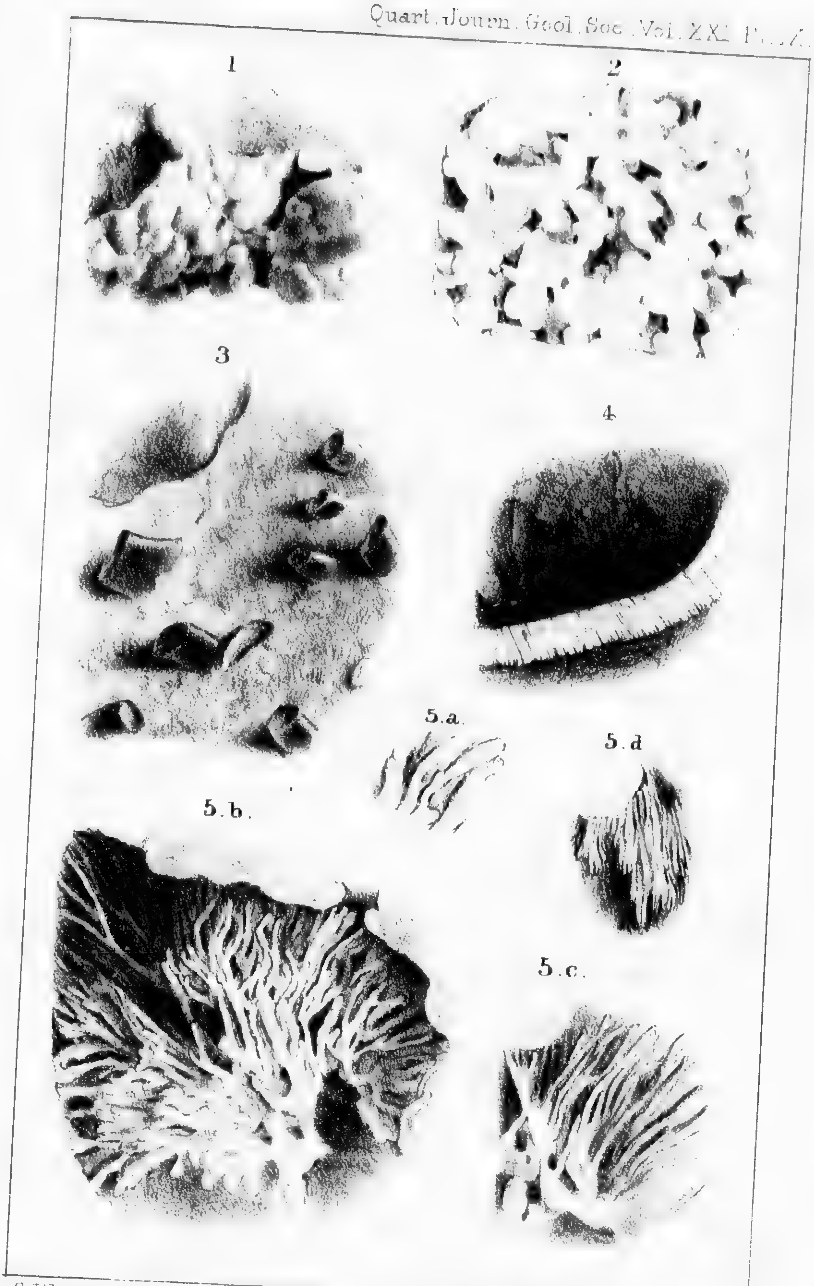
4. Acicular casts from Nummuline wall of chamber: magnified 100 diameters.

5. Casts of interior of canal-system:—*a*, portion of large, magnified 25 diameters; *b*, entire group of the same, magnified 10 diameters; *c*, medium, *d*, small, magnified 25 diameters.

G. West, lith.

EOZOÖN CANADENSE.

M & N Hanhart, Imp.



G. West, lith.

EOZOON CANADENSE. Dawson.

M & N Hanhart Imp.

4. *On the* Mineralogy *of* certain Organic Remains *from the* Laurentian Rocks *of* Canada. By T. Sterry Hunt, Esq., M.A., F.R.S.

[Communicated by Sir W. E. Logan, LL.D., F.R.S., F.G.S.]

The remains of *Eozoön Canadense*, a Foraminiferal organism recently discovered in the Laurentian limestones of Canada, present an interesting subject of study, both to the mineralogist and the geologist. For a zoological description of this organic form the reader is referred to the preceding description by Dr. Dawson.

The details of structure have been preserved by the introduction of certain mineral silicates, which have not only filled up the chambers, cells, and canals left vacant by the disappearance of the animal matter, but have in very many cases been injected into the tubuli, filling even their smallest ramifications. These silicates have thus taken the place of the original sarcode, while the calcareous septa remain. It will then be understood that when the replacement of the *Eozoön* by silicates is spoken of, this is to be understood of the soft parts only, since the calcareous skeleton is preserved, in most cases, without any alteration. The vacant spaces left by the decay of the sarcode may be supposed to have been filled by a process of infiltration, in which the silicates were deposited from solution in water, like the silica which fills up the pores of wood in the process of silicification. The replacing silicates, so far as yet observed, are a white pyroxene, a pale-green serpentine, and a dark-green alumino-magnesian mineral, which is allied in composition to chlorite and to pyrosclerite, and which I have referred to loganite. The calcareous septa in the last case are found to be dolomitic, but in the other instances are nearly pure carbonate of lime. The relations of the carbonate and the silicates are well seen in thin sections under the microscope, especially by polarized light. The calcite, dolomite, and pyroxene exhibit their crystalline structure to the unaided eye; and the serpentine and logamite are also seen to be crystalline when examined with the microscope. When portions of the fossil are submitted to the action of an acid, the carbonate of lime is dissolved, and a coherent mass of serpentine is obtained, which is a perfect cast of the soft parts of the *Eozoön*. The form of the sarcode which filled the chambers and cells is beautifully shown, as well as the connecting canals and the groups of tubuli; these latter are seen in great perfection upon surfaces from which the carbonate of lime has been partially dissolved. Their preservation is generally most complete when the replacing mineral is serpentine, although very perfect specimens are sometimes found in pyroxene. The crystallization of the later mineral appears, however, in most cases to have disturbed the calcareous septa.

Serpentine and pyroxene are generally associated in these specimens, as if their deposition had marked different stages of a continuous process. At the Calumet, one specimen of the fossil exhibits the whole of the sarcode replaced by serpentine; while, in another one from the same locality, a layer of pale-green translucent serpentine occurs in immediate contact with the white pyroxene.

The calcareous septa in this specimen are very thin, and are transverse to the plane of contact of the two minerals; yet they are seen to traverse both the pyroxene and the serpentine without any interruption or change. Some sections exhibit these two minerals filling adjacent cells, or even portions of the same cell, a clear line of division being visible between them. In the specimens from Grenville, on the other hand, it would seem as if the development of the *Eozoön* (considerable masses of which were replaced by pyroxene) had been interrupted, and that a second growth of the animal, which was replaced by serpentine, had taken place upon the older masses, filling up their interstices.

The results of the chemical examination of these fossils from different localities may now be given:—I. A specimen of *Eozoön* from the Calumet, remarkable for the regularity of its laminated arrangement, gave to warm acetic acid 27·0 per cent. of soluble matter, consisting of carbonate of lime 97·1. carbonate of magnesia 2·9=100. II. Another specimen of the fossil, from Grenville, replaced by pyroxene, yielded in the same way 12·0 per cent. of soluble matter, which was composed of carbonate of lime 98·7, carbonate of magnesia 1·3=100. III. In this specimen of the fossil, which adjoined the last, serpentine was the replacing mineral. The soluble portion from this equalled 47·0 per cent., and consisted of carbonate of lime 96·0, carbonate of magnesia 4·0=100. It thus appears that the septa in these specimens of *Eozoön* are nearly pure carbonate of lime. The somewhat larger proportion of magnesia from the last is due to the use, as a solvent, of dilute nitric acid, which slightly attacked the serpentine.

The pyroxene of the above specimens is a very pure silicate of lime and magnesia; that from I. gave, by analysis, silica 54·90, lime 27·67, magnesia 16·76, volatile matter 0·80=100·13. A partial analysis of the pyroxene from II. yielded lime 28·3, magnesia 13·8. This specimen was interpenetrated with serpentine, amounting to about 10·0 per cent., which was first removed by the successive action of heated sulphuric acid and dilute soda-ley. The serpentine from III. yielded silica 42-85, magnesia 41·68, protoxide of iron 0·67, water 13·89=99·09. As already mentioned, this serpentine had lost a little magnesia from the action of nitric acid; a similar serpentine from the Calumet, associated with the *Eozoön*, gave silica 41·20, magnesia 43·52, protoxide of iron 0·80, water 15·40=100·92. These serpentines from the Laurentian limestones are remarkable for their freedom from iron-oxide, for their large amount of water, and their low specific gravity*.

Specimens of *Eozoön* from Burgess differ from the foregoing in the composition both of the replacing material and the septa. The latter consist of a somewhat ferriferous dolomite, the analysis of which was made upon portions mechanically separated from the enclosed silicate; it yielded carbonate of magnesia 40·7, carbonate of lime, with a little peroxide of iron, 59·0=99·7. The septa of the

* See my descriptions, 'American Journal of Science,' 2nd ser. vol. xxvi. p. 236.

specimen from this locality are in some parts more than 3·0 millimetres in thickness, and exhibit the chambers, cells, and septal orifices; but no tubuli are seen. The replacing material has the hardness of serpentine, for which it was at first mistaken. Its colour is blackish-green, but olive-green in thin sections, when it is seen by transmitted light to be crystalline in texture. Its fracture is granular, and its lustre feebly shining. It is decomposed by heated sulphuric acid, and was thus analysed, yielding the result I. The centesimal composition of the soluble portion is given under II.

	I.	II.	III.
Silica	33·75	35·14	36·50
Alumina	9·75	10·15	10·80
Magnesia	30·24	31·47	28·20
Protoxide of iron	8·19	8·60	9·54
Water	14·08	14·64	14·62
Insoluble sand	2·50	—	—
	98·51	100·00	99·66

The silicate which here takes the place of the pyroxene and serpentine observed in the other specimens of *Eozoön* is one of frequent occurrence in the Laurentian limestones, and appears to constitute a distinct species, which I long since described under the name of loganite, and which occurs at the Calumet in dark brown prismatic crystals*. I have since observed a similar mineral in two other localities besides the one here noticed. The result III., which is placed by the side of the analysis of the Burgess fossil, was obtained with a greenish-grey sparry prismatic variety from North Elmsley, having a hardness of 3·0, and a specific gravity of 2·539†. These hydrous alumino-magnesian silicates, which I have there included under the name of loganite, are related to chlorate and to pyrosclerite in composition, but are distinguished by their eminently foliated micaceous structure.

When examined under the microscope, the loganite, which replaces the *Eozoön* of Burgess, shows traces of cleavage-lines, which indicate a crystalline structure. The grains of insoluble matter found in the analysis, chiefly of quartz-sand, are distinctly seen as foreign bodies embedded in the mass, which is moreover marked by lines apparently due to cracks formed by a shrinking of the silicate, and subsequently filled by a further infiltration of the same material. This arrangement resembles on a minute scale that of septaria. Similar appearances are also observed in the serpentine which replaces the *Eozoön* of Grenville, and also in a massive serpentine from Burgess resembling this, and enclosing fragments of the fossil. In both of these specimens also grains of mechanical impurities are detected by the microscope, which are, however, rarer than in the loganite of Burgess.

From the above facts it may be concluded that the various sili-

* Phil. Mag. 4th ser. vol. ii. p. 65.

† For a description of this and similar silicates, see 'Geology of Canada,' p. 491.

cates which now constitute pyroxene, serpentine, and loganite were directly deposited in waters in the midst of which the *Eozoön* was still growing or had only recently perished, and that these silicates penetrated, enclosed, and preserved the calcareous structure precisely as carbonate of lime might have done. The association of the silicates with the *Eozoön* is only accidental, and large quantities of them, deposited at the same time, include no organic remains. Thus, for example, there are found associated with the Eozoön-limestones of Grenville massive layers and concretions of pure serpentine; and a serpentine from Burgess has already been mentioned as containing only small broken fragments of the fossil. In like manner large masses of white pyroxene, often surrounded by serpentine, both of which are destitute of traces of organic structure, are found in the limestones at the Calumet. In some cases, however, the crystallization of the pyroxene has given rise to considerable cleavage-planes, and has thus obliterated the organic structure from masses which, judging from portions visible here and there, appear to have been at one time penetrated by the calcareous plates of *Eozoön*. Small irregular veins of crystalline calcite, and of serpentine, are found to traverse* such pyroxenic masses in the Eozoön-limestone of Grenville.

As already mentioned in Sir W. E. Logan's description, it appears that great beds of the Laurentian limestones are composed of the ruins of the *Eozoön*. These rocks, which are white, crystalline, and mingled with pale green serpentine, are similar in aspect to many of the so-called primary limestones of other regions. In most cases the limestones are non-magnesian, but one of them from Grenville was found to be dolomitic. The accompanying strata often present finely crystallized pyroxene, hornblende, phlogopite, apatite, and other minerals. These observations bring the formation of siliceous minerals face to face with life, and show that their generation was not incompatible with the contemporaneous existence and the preservation of organic forms. They confirm, moreover, the view which I some years since put forward, that these silicated minerals have been formed, not by subsequent metamorphism in deeply buried sediments, but by reactions going on at the earth's surface†. In support of this view, I have elsewhere referred to the deposition of silicates of lime, magnesia, and iron from natural waters, to the great beds of sepiolite in the unaltered Tertiary strata of Europe, to the contemporaneous formation of neolite (an alumino-magnesian silicate related to loganite and chlorite in composition), and to glauconite, which occurs not only in Secondary, Tertiary, and Recent deposits, but also, as I have shown, in Lower Silurian strata‡. This hydrous

* Recent examinations have shown that some of these masses encrusted with *Eozoön*, replaced by serpentine, consist of crystalline pyrallolite (rensselaerite), which seems, like the other silicates, to have replaced the organic matter of the Rhizopod. Further examinations, aided by the microscope, are however needed to determine with certainty the relations of the *Eozoön* to these masses of pyrallolite.

† Amer. Journ. Science, 2nd ser. vol. xxix. p. 284; vol. xxxii. p. 286. Geology of Canada, p. 577.

‡ Amer. Journ. Science, 2nd ser. vol. xxxiii. p. 277. Geology of Canada, p. 487.

silicate of protoxide of iron and potash, which sometimes includes a considerable proportion of alumina in its composition, has been observed by Ehrenberg, Mantell, and Bailey, associated with organic forms in a manner which seems identical with that in which pyroxene, serpentine, and loganite occur with the *Eozoön* in the Laurentian limestones. According to the first of these observers, the grains of greensand, or glauconite, from the Tertiary limestone of Alabama are casts of the interior of Polythalamia, the glauconite having filled them by "a species of natural injection, which is often so perfect that not only the large and coarse cells, but also the very finest canals of the cell-walls and all their connecting tubes are thus petrified and separately exhibited." Bailey confirmed these observations, and extended them. He found in various Cretaceous and Tertiary limestones of the United States, casts in glauconite, not only of *Foraminifera*, but of spines of *Echinus* and of the cavities of Corals. Besides, there were numerous red, green, and white casts of minute anastomosing tubuli, which, according to Bailey, resemble casts of the holes made by burrowing Sponges (*Cliona*) and Worms. These forms are seen after dissolving the carbonate of lime by a dilute acid. He found, moreover, similar casts of *Foraminifera*, of minute Mollusks, and of branching tubuli, in mud obtained from soundings in the Gulf-stream, and concluded that the deposition of glauconite is still going on in the depths of the sea*. Pourtales has followed up these investigations on the recent formation of glauconite in the Gulf-stream waters. He has observed its deposition also in the cavities of *Millepores*, and in the canals in the shells of *Balanus*. According to him the glauconite-grains formed in *Foraminifera* lose after a time their calcareous envelopes, and finally become "conglomerated into small black pebbles," sections of which still show under a microscope the characteristic spiral arrangement of the cells†.

It appears probable from these observations that glauconite is formed by chemical reactions in the ooze at the bottom of the sea, where dissolved silica comes in contact with iron-oxide rendered soluble by organic matter; the resulting silicate deposits itself in the cavities of shells and other vacant spaces. A process analogous to this, in its results, has filled the chambers and canals of the Laurentian *Foraminifera* with other silicates; from the comparative rarity of mechanical impurities in the silicates, however, it would appear that they were deposited in clear water. Alumina and oxide of iron enter into the composition of loganite as well as of glauconite; but in the other replacing minerals, pyroxene and serpentine, we have only silicates of lime and magnesia, which were probably formed by the direct action of alkaline silicates, either dissolved in surface-waters or in those of submarine springs, upon the calcareous and magnesian salts of the sea-water. Experiments undertaken with the view of determining the precise conditions under which these and similar silicates may thus be formed are now in progress.

* Amer. Journ. Science, 2nd ser. vol. xxii. p. 280.

† Rep. Amer. Coast-Survey, 1858, p. 248.